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This research attempts to develop a fundamental understanding of the issues involved in the design and performance analysis of distributed detection schemes. Such knowledge is currently lacking. This is especially true for cases with statistically dependent observations from sensor to sensor, a practical case on which this research focuses. Some emphasis is being devoted to developing design algorithms and to the study of nonparametric distributed detection schemes for cases with uncertain statistical models. The goal of these studies is to produce tools and techniques for pressing practical problems. We classify our efforts into three basic areas: optimum distributed detection for dependent observations cases, design algorithms, applications and image fusion.

1 Dependent Observations Cases

Very little was known about the properties of optimum distributed detection schemes for cases with dependent observations. For centralized detection cases, likelihood ratio tests are always optimum. This suggested an interesting question. When are likelihood ratio tests optimum at distributed sensors? For the case of correlated Gaussian noise, we were able to obtain conditions under which this must occur and conditions under which this can not occur [1]. NonGaussian noise cases were considered in another series of papers [2,3], where we found this problem is considerably more complex. However the optimum detectors follow a pattern which can be used to predict the general forms of the optimum processing without complex computations.

2 Design Algorithms

We have determined some new discretized Gauss-Seidel type algorithms for finding Bayesian optimum distributed detection schemes [4]. We have further proven that these algorithms converge in a finite number of iterations. In the process of studying these algorithms we made an exciting discovery on the properties of optimum distributed schemes [4]. Given a distributed scheme which uses a given number of bits for the decisions at all but the last sensor, we can show that the last sensor should not use more than a certain number of bits in its decision. If more bits are used at the last sensor, then the same performance can be obtained by using less bits, which implies lower speed communications. The results in [4] are extended in [5] for cases with more than two hypothesis. In [5], we also show that in some common cases, the maximum number of bits that should

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13. ABSTRACT (Maximum 200 Words)
This research attempts to develop a fundamental understanding of the issues involved in the design and performance analysis of distributed signal detection schemes. Such knowledge is currently lacking. This is especially true for cases with statistically dependent observations from sensor to sensor, a practical case on which this research focuses. Some emphasis is being devoted to developing design algorithms, applications, and algorithms for image fusion. The goal of these studies is to produce tools and techniques for pressing practical problems. This report describes the progress made in the last year. The investigation produced several significant results that illustrate how little is really known about the underlying theory of distributed signal detection. For example, given a distributed scheme which uses a given number of bits for the decisions at all but the last sensor, we can show that the last sensor should not use more than a certain number of bits in its decision. If more bits are used at the last sensor, then the same performance can be obtained by using less bits, which implies lower speed communications.

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May 17, 1999

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Re: "Year End Progress Report for ONR Young Investigator Grant N00014-97-1-0774 ", by Rick S. Blum.

Dr. Madan,

I am pleased to report to you on the excellent progress we have made in the past year. I am enclosing three copies of our "Year End Progress Report for ONR Young Investigator Grant N00014-97-1-0774 ". As per the instructions I received, I am sending the required copies to my administrative grants officer, NRL, and DTIC.

Sincerely,

Rick S. Blum

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be used at a given sensor are much less the number given in [4]. This is true for the important case of known signals in uncorrelated Gaussian noise. It is even true in many cases with correlated Gaussian noise.

The Neyman Pearson criterion has been a subject of much controversy and confusion when studied for distributed detection cases. For example, several researchers have claimed some results produced by other researchers are incorrect. While none of our papers were involved in this controversy, the exchanges of the other researchers motivated us to attempt to uncover the truth. In a very recent paper [6], we have finally clarified the confusion and proved some Theorems that clearly describe the true situation. The Theorems describe methods for finding optimum distributed detection systems.

3 Applications

Investigating practical applications of distributed signal detection is an area in which we have devoted considerable effort. One application involves fusing the data obtained from multiple surveillance systems to achieve improved performance. Testbeds have been constructed at a number of DoD laboratories. Another important application involves the design of wireless communication receivers. We have recently obtained some analytical results [7] which suggest that distributed processing techniques can reduce the complexity of wireless communication receivers without significant loss in performance. Our initial investigations [7] have focused on frequency shift keying modulation. More recently, we have considered more complicated modulation schemes, including frequency hopped spread spectrum approaches [8]. A related contribution on sequence estimation [9] emerged from these investigations.

4 Image Fusion

The objective of image fusion is to combine information from multiple images of the same scene. The result of image fusion is a single image which is more suitable for human and machine perception or further image processing tasks. In our research [10,11], a generic image fusion framework based on multiscale decomposition is studied. This framework provides freedom to choose different multiscale decomposition methods and different fusion rules. The framework includes all of the existing multiscale-decomposition-based fusion approaches we found in the literature which did not assume a statistical model for the source images. Different image fusion approaches are investigated based on this framework. Some evaluation measures are suggested and applied to compare the performance of these fusion schemes. The majority of the research focuses on fusing same sensor images. In particular, visual images are used in the majority of the tests. The comparisons indicate that our framework includes some new approaches which outperform the existing approaches for the cases we consider. More recently, we have studied algorithms to measure fusion quality [12], for image registration for fusion [11], and for fusion of omni-camera images [11].

5 Contributions

The project has made significant contributions to the field of Electrical Engineering and in particular to the study of distributed signal processing systems. The main contributions have been towards developing the fundamental theory of this topic, which has been lacking. Such studies should stimulate future breakthroughs. Although we did realize this theory was not in place, even we were amazed at the basic nature of some of our results. It was surprising that results of this

type were new. This illustrated to us how little is really known about the underlying theory of distributed signal processing. For example, prior to our work it was not known that the number of sensor decision bits used at one sensor can limit the number that should be used at another sensor. This is a very basic property that relies heavily on the nonuniqueness of the overall decision rule realized by a particular set of sensor rules and a fusion rule. Although the result makes sense to us now, even we were surprised by this finding. We were also surprised by the number of errors and misconceptions in the existing theory for Neyman-Pearson optimum distributed signal detection. We believe that our work on this topic will lead to numerous new developments and theory. Prior to this the theory of Neyman-Pearson optimum distributed schemes was thought to be extremely hard to develop for dependent observation cases. Our recent results indicate this theory may not be so difficult to develop.

Since our results are at such a basic level, we believe they have contributed to many disciplines and in particular to the broad topic of data fusion which spans many areas of science and engineering. We outline here the areas we expect will benefit from this research. The theory of distributed decision making is important in many areas outside Electrical Engineering. It has applications in any area involving team decision making by groups of smart machines or humans. Particular application areas include financial institutions, air-traffic control, oil exploration, medical diagnosis, military command and control, electric power networks, weather prediction, manufacturing, computer-based navigation systems, law enforcement, robotics, and industrial organizations. Our basic theory on how to design distributed decision making systems should influence developments in these application areas. We should mention that our topic is closely related to an important type of data fusion, called decision fusion, that has its roots in robotics, artificial intelligence, mathematics, information theory and computing. We have been interfacing with these communities through the Fusion conferences (Fusion 98 and Fusion 99) which have been held the last few years. We have been active in running this conference and in organizing a multidisciplinary Data Fusion Society.

We have trained PhD level researchers for the signal processing, communications and computing industries, areas where highly trained personnel are desperately needed. Wherever possible, we have encouraged these researchers to consider faculty positions. In cases where interest exists the student has been trained and mentored specifically for this purpose since we believe developing highly qualified faculty members is an important role for a University. It is also very important for the future success of our nation. One PhD student finished this year, one will finish over the summer and three more students will finish next school year.

Clearly we are proud our our strong theoretical contributions, but we are also proud of the more practical contributions we have made. We have developed practical design algorithms for distributed signal detection systems and we have demonstrated the applications of our theory to wireless communication receivers. We are aware of several experimental surveillance systems constructed at several laboratories. The designers have struggled due to a lack of theory for the design of these systems. Our results should be helpful in this regard. We have also convinced personnel at Lucent Technologies that our ideas could be applied in the implementation of practical communication receivers. We hope to initiate a directed study along these line in the near future using funding from Lucent Technologies.

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